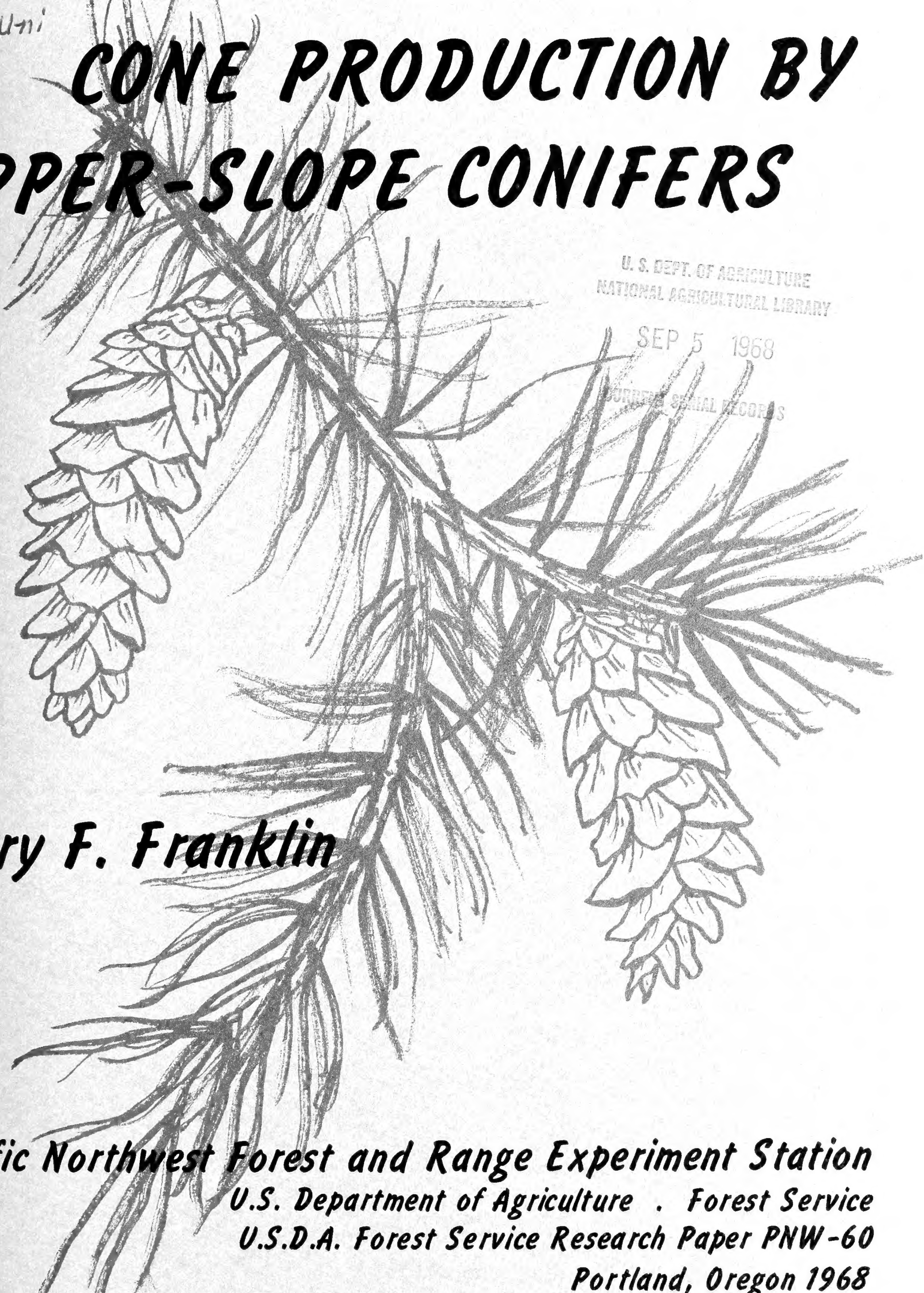
CONE PRODUCTION BY UPPER-SLOPE CONIFERS



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CONTENTS

INTRODUCTION

Seed supply and seedling survival are the two key features of any silvicultural system utilizing natural regeneration. Infrequent occurrence of good crops could restrict the potential for natural regeneration or necessitate cutting methods which provide seed over a long timespan.

Investigation of seed supply in upper-slope, true fir-hemlock forests of the Pacific Northwest began in 1961 with establishment of a long-term cone production study. Since then, annual cone counts have been made of mature specimens of noble fir *(Abies procera),* Pacific silver fir *(A. amabilis),* mountain hemlock *(Tsuga mertensiana),* and western white pine *(Pinus monticola)* throughout the mountains of western Oregon and Washington. More limited observations of cone production by subalpine fir *(Abies lasiocarpa),* grand fir *(A. grandis),* Shasta red fir *(A. magnifica* var. *shastensis),*[1] and Engelmann spruce *(Picea engelmannii)* have also been obtained.

This paper is a progress report on cone-bearing habits of these upper-slope tree species. Some silvicultural implications of the data are also provided.

[1] Shasta red fir in southern Oregon is a morphologically variable complex sometimes referred to as noble fir. Populations may constitute hybrid swarms resulting from mingling of noble and California red firs *(Abies magnifica),* in which case none of the present taxonomic designations are correct. However, because of ecological differences between the southern Oregon true fir and the noble fir found in Washington and northern Oregon, and until the identity of the former has been satisfactorily established by taxonomic study, the southern Oregon true fir will be referred to as Shasta red fir.

THE STUDY

A total of 47 plots have been established and studied since 1961, the majority now providing a 6-year record of cone production. The location and elevation of these plots, characteristics of the sample trees, and period of observation are listed in table 1. The geographic distribution of study plots is illustrated in figure 1. The majority of plots are for key upper-slope species: Pacific silver fir (12 plots), noble fir (eight plots), mountain hemlock (seven plots), and western white pine (nine plots), one of which was lost to mountain pine beetle 2 years after establishment). The remainder are divided between grand, Shasta red, and subalpine firs and Engelmann spruce. In several instances, "plots" are located in the same stand, e.g., grand fir, subalpine fir, western white pine, and Engelmann spruce at Big Meadows Creek. No records of cone production by upper-slope Douglas-fir and western hemlock were taken.

Field Methods

The study began with selection of relatively compact and mature stands of upper-slope species. To obtain a good cross section of yearly geographic variation in cone production, locales were selected throughout the western Oregon and Washington ranges of the major tree species. Most stands sampled were necessarily along stabilized clearcut boundaries or road rights-of-way to obtain good views of the crowns for counting purposes. Since the major purpose of the study was to observe yearly variation in cone production, edge effects were not considered important.

Table 1.--Location of the study plots, characteristics of the sample trees, and length of cone production record, as of 1967

Species	Locality	Ranger District and National Forest	Ecological province[1]	Elevation	Sample trees: Number	Sample trees: Average height	Sample trees: Average d.b.h.	Sample trees: Average age	Years of record
				Feet		*Feet*	*Inches*	*Years*	
Pacific silver fir	Glacier Creek No. 1	Glacier Mount Baker	Mount Baker	3,700	27	160	23.7	125	7
	Glacier Creek No. 2	Glacier, Mount Baker	Mount Baker	4,000	23	180	36.4	325	5
	Tunnel Creek	Skykomish, Snoqualmie	Mount Baker	2,750	21	185	45.0	250	5
	Stampede Pass	Cle Elum, Wenatchee	Mount Rainier	3,600	33	145	22.7	175	6
	Mosquito Lakes	Mount Adams, Gifford Pinchot	Mount Adams	3,900	21	130	27.3	200	6
	Spirit Lake	St. Helens, Gifford Pinchot	Mount Rainier	3,250	4	140	27.0	120	5
	Bare Mountain	St. Helens, Gifford Pinchot	Mount Rainier	4,000	22	125	25.8	325	6
	Timberline Road	Zigzag, Mount Hood	Mount Hood	4,500	17	110	27.0	250	6
	Santiam Pass	McKenzie, Willamette	Three Sisters	4,750	24	100	17.8	150	6
	Iron Mountain	Sweet Home, Willamette	Willamette	5,200	21	80	21.7	100	6
	Hunger Mountain	Sol Duc, Olympic	Olympic	3,000	22	185	38.6	175	6
	Bon Jon Pass	Quilcene, Olympic	Olympic	3,500	26	125	25.3	135	6
Noble fir	Tunnel Creek	Skykomish, Snoqualmie	Mount Baker	2,750	19	220	51.6	225	7
	Stampede Pass	Cle Elum, Wenatchee	Mount Rainier	3,600	22	155	31.3	175	7
	Willame Creek	Packwood, Gifford Pinchot	Mount Rainier	4,000	22	215	58.0	225	6
	Spirit Lake	St. Helens, Gifford Pinchot	Mount Rainier	3,250	31	155	32.0	115	5
	Sleeping Beauty	Mount Adams, Gifford Pinchot	Mount Adams	4,000	21	160	31.3	200	6
	North Wilson	Bear Springs, Mount Hood	Mount Hood	4,500	24	145	33.4	250	6
	Wildcat Mountain	McKenzie, Willamette	Willamette	4,250	20	170	42.4	115	6
	Marys Peak	Alsea, Siuslaw	Coast Ranges	3,700	30	150	46.7	175	6
Mountain hemlock	Heather Meadows	Glacier, Mount Baker	Mount Baker	3,850	17	80	24.3	250	6
	Stampede Pass	Cle Elum, Wenatchee	Mount Rainier	3,600	23	130	20.2	225	6
Mountain hemlock	Steamboat Mountain	Mount Adams, Gifford Pinchot	Mount Adams	5,000	18	50	18.5	175	6
	Deadman's Curve	Zigzag, Mount Hood	Mount Hood	4,500	19	100	21.6	250	6

[1] See Franklin (1965).

Table 1.--Location of the study plots, characteristics of the sample trees, and length of cone production record, as of 1967--Continued

Species	Locality	Ranger District and National Forest	Ecological province[1]	Elevation	Sample trees				Years of record
					Number	Average height	Average d.b.h.	Average age	
				Feet		*Feet*	*Inches*	*Years*	
	Santiam Pass	McKenzie, Willamette	Three Sisters	4,750	20	105	22.4	200	6
	Carpenter Mountain	Blue River, Willamette	Willamette	5,300	21	85	23.0	125	6
	Windigo Pass	Diamond Lake, Umpqua	Crater Lake	5,250	21	125	19.8	225	6
Western white pine	Lake Wenatchee	Lake Wenatchee, Wenatchee	Wenatchee	2,400	0	210	34.2	175	2
	Big Meadows Creek	Lake Wenatchee, Wenatchee	Wenatchee	2,400	15	200	28.4	125	5
	Smithbrook	Lake Wenatchee, Wenatchee	Mount Baker	3,300	18	140	34.5	150	4
	Peterson Prairie	Mount Adams, Gifford Pinchot	Mount Adams	3,000	19	115	21.0	75	6
	Bear Paw	Bear Springs, Mount Hood	Mount Hood	2,350	25	95	15.2	75	6
	Santiam Pass	McKenzie, Willamette	Three Sisters	4,750	20	115	29.0	110	6
	Lost Prairie	Sweet Home, Willamette	Willamette	3,325	7	160	32.0	105	5
	Windigo Pass	Diamond Lake, Umpqua	Crater Lake	5,250	21	135	26.1	250	6
	Bessie Rock	Prospect, Rogue River	Crater Lake	5,400	15	140	25.4	225	2
Subalpine fir	Big Meadows Creek	Lake Wenatchee, Wenatchee	Wenatchee	2,400	18	165	24.4	150	5
	Smithbrook	Lake Wenatchee, Wenatchee	Mount Baker	3,300	24	115	30.0	125	4
	Steamboat Mountain	Mount Adams, Gifford Pinchot	Mount Adams	5,300	25	85	19.7	150	6
	Sand Mountain	McKenzie, Willamette	Three Sisters	5,200	30	40	8.7	50	6
Grand fir	Big Meadows Creek	Lake Wenatchee, Wenatchee	Wenatchee	2,400	20	160	31.2	150	5
	Peterson Prairie	Mount Adams, Gifford Pinchot	Mount Adams	3,000	23	75	23.0	125	5
	Lost Prairie	Sweet Home, Willamette	Willamette	3,325	20	155	31.1	120	5
Shasta red fir	Windigo Pass	Diamond Lake, Umpqua	Three Sisters	5,250	21	135	29.1	250	6
	Bessie Rock	Prospect, Rogue River	Three Sisters	5,400	30	150	32.9	225	2
Engelmann spruce	Big Meadows Creek	Lake Wenatchee, Wenatchee	Wenatchee	2,400	16	165	30.5	150	5
	Lost Lake Creek	McKenzie, Willamette	Three Sisters	4,250	20	140	31.8	125	5

[1] See Franklin (1965).

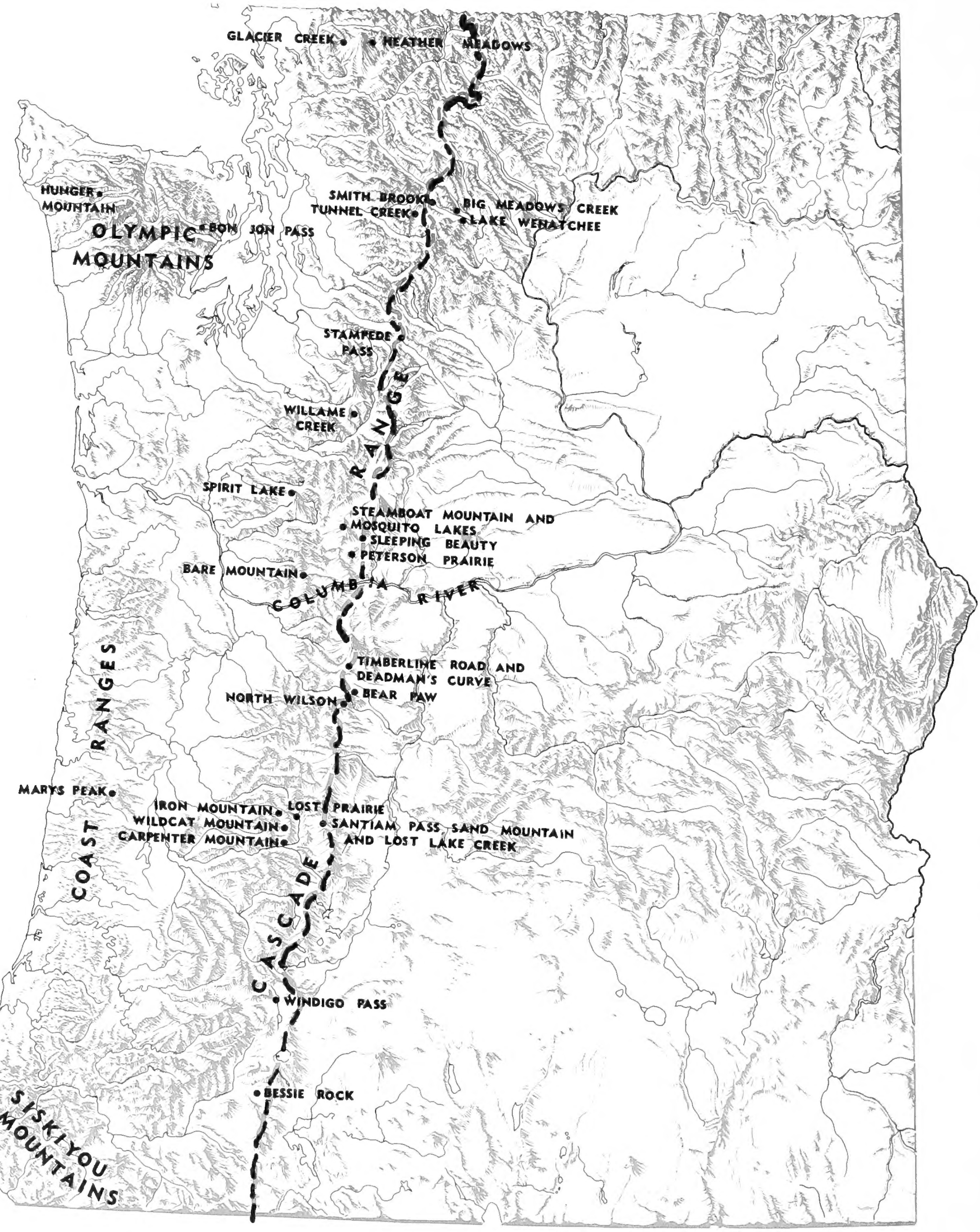

Figure 1.–Geographic distribution of cone production study plots.

Differences in cone production between trees on the stand edge and within the stand were not observed.

Once a suitable stand was located, usually 15 to 30 trees of each species being sampled were selected. Sample trees were dominants with an undamaged upper crown, one side of which was readily observable for cone counting purposes. Only dominant trees were used since many studies have shown that these are the trees that produce three-fourths or more of all cones (Fowells and Schubert 1956; Haig et al. 1941).[2] Each tree was tagged, measured, and marked with a large spray-painted number for identification from a distance. At the same time, observation or counting points were selected for each tree, and adjacent logs, stumps, or trees were marked with paint. A sketch map aided in relocation of these counting points in later years.

Using binoculars or a variable 15- to 60-power spotting scope, we counted yearly all visible cones from the identical, single counting point selected for the tree. Binoculars were used during the first 3 years of the study (1961-63), and the spotting scope has usually been used since. A small-scale test revealed no consistent differences in counts between the binoculars and spotting scope, but it was easier and faster to obtain accurate counts using the scope. The author made approximately two-thirds of the cone counts himself. Observations by four others, who assisted in the study, were checked against those of the author, but they did not differ consistently nor by more than ± 5 percent. An observer correction factor was, therefore, not used.

[2] Names and dates in parentheses refer to Literature Cited, p. 21.

Two problems were encountered in counting mountain hemlock cones. First, it was difficult to obtain accurate counts of the abundant, densely clustered, relatively small cones during years of heavy production. Observers sometimes had to count individual branches and multiply these values by number of similarly laden branches to obtain total counts. Second, some mountain hemlock cones are retained in tree crowns for at least 2 or 3 years after shedding their seed. Counts must be made while new cones are still tightly closed and distinctive from the old cones, yet not so early that the new cones are too small to be readily and accurately counted.

Presentation of Data

Data reported are based on the number of cones counted from a single and constant observation point for each tree. Total cone production was greater as many cones are hidden by foliage, limbs, or the main stem. Fowells and Schubert (1956) used a factor of 1.5 to convert individual cone counts of sugar and ponderosa pines and white fir from a single observation point to total cone production. Two-thirds of the crown was assumed to be visible from a single point. By counting cones before and after felling, Wenger (1953), Hoekstra (1960), and Garman (1951) found a cone count conversion factor of around 2 was needed for the species they worked with – loblolly pine, slash pine, and Douglas-fir, respectively. Converting factors are presently being developed for the upper-slope species under study. Total cone production may be calculated by the following tentatively suggested factors,

based on available data and size and position of the cones in the crown:

Noble and Shasta red firs and western white pine	1.5
Pacific silver, grand, and subalpine firs	1.7
Mountain hemlock and Engelmann spruce	2.0

In tabulations of data and rating of cone crops, median cone counts for plots are emphasized, although the plot means and the range of individual tree counts on each plot are also given. The median observation is the middle one when cone counts are arranged in order of magnitude. Half of the counts are less than this value and half are greater (except in the case of zero median values). Medians are used because they are considered more representative of cone production by the "typical" study tree than the mean cone count for the plot. Production of large numbers of cones by one or two trees on a plot in a generally poor year results in relatively large average plot values, even if a majority of trees experienced a failure or very light crops.

It is convenient in discussing cone data to use general categories for cone production – failures, medium crops, very heavy crops, etc. A cone crop rating system based on the median cone count was developed to put the terms used on a quantitative basis (table 2). Considerations of number of seeds per cone and the range in cone production commonly encountered resulted in differences between species in rating definition. The reader should note the system is based on median cone counts of a sample of dominant trees. It can be applied as well to individual trees, however.

RESULTS AND DISCUSSION

Cone Production by Species

Noble fir.--Noble fir proved to be a prolific cone producer on most of the study plots (table 3). According to the "Woody-Plant Seed Manual" (U.S. Forest Service 1948), noble fir produces good crops at infrequent intervals and some seed every year. This statement is accurate when all plots are considered together. However, one stand (Willame Creek) mustered heavy or very heavy crops 4 years out of 6 and another (North Wilson) produced a single medium crop during 6 years of observation. The relatively high cone production at Tunnel Creek is noteworthy since this plot is near the northern limits of noble fir.

Variation in cone production between localities during a given year was considerable. The year 1962 was generally good, and 1964 was universally poor. In 1965, on the other hand, four plots produced very heavy crops and the other four almost no cones.

Cone failures the year after a heavy or very heavy crop were not universal. An analysis of 48 years of Douglas-fir cone crop records showed that abundant years were always followed by failures or light crops (Lowry 1966). The seven records of very heavy noble fir crops (e.g., Tunnel Creek in 1962) were succeeded by failures three times but by very light, light, medium, and heavy crops (Willame Creek in 1966) in the other four instances. An

Table 2.--Cone crop rating system based on median count of a sample of dominant trees, cone counts to be made from a single observation point per tree

Species	Crop rating	Median number of cones per tree
Noble, Pacific silver, and Shasta red firs and western white pine	Failure	0
	Very light	1-4
	Light	5-9
	Medium	10-19
	Heavy	20-49
	Very heavy	50+
Grand and subalpine firs	Failure	0
	Very light	1-9
	Light	10-19
	Medium	20-49
	Heavy	50-99
	Very heavy	100+
Engelmann spruce and mountain hemlock	Failure	0-10
	Very light	11-49
	Light	50-99
	Medium	100-199
	Heavy	200-299
	Very heavy	300+

Table 3.--Noble fir cone counts by location and year[1]

Year	Tunnel Creek	Stampede Pass	Willame Creek	Sleeping Beauty	Spirit Lake	North Wilson	Wildcat Mountain	Marys Peak	Average
	Number[2]								
1961	21	32	–	–	–	–	–	–	26.5
1962	270	15	47	16	–	1	83	76	72.6
1963	0	0	24	0	4	0	10	0	4.8
1964	5	2	2	0	0	0	3	1	1.6
1965	1	0	184	0	77	0	172	112	68.3
1966	24	0	40	16	8	0	0	4	11.5
1967	0	6	2	0	0	12	10	4	4.2
Average, 1961-67	45.9	7.9	49.8	5.3	17.8	2.6	46.3	32.8	
	Number and range[3]								
1961	61 (0-286)	41 (6-36)	–	–	–	–	–	–	51.0
1962	343 (90-850)	19 (0-78)	67 (0-300)	24 (4-56)	–	4 (1-15)	98 (24-316)	92 (28-413)	91.0
1963	1 (0-12)	0 (0-2)	41 (0-354)	0 (0-0)	8 (0-57)	0 (0-0)	18 (0-118)	6 (0-44)	9.3
1964	14 (0-55)	8 (0-51)	6 (0-29)	2 (0-11)	7 (0-77)	1 (0-6)	7 (0-39)	3 (0-21)	6.0
1965	15 (0-92)	0 (0-0)	200 (48-465)	1 (0-11)	91 (18-313)	0 (0-0)	222 (50-784)	174 (36-960)	87.9
1966	83 (0-630)	5 (0-95)	56 (6-290)	28 (7-137)	12 (0-119)	1 (0-11)	0 (0-0)	8 (0-41)	24.1
1967	2 (0-23)	17 (0-86)	3 (0-14)	2 (0-13)	3 (0-27)	19 (0-109)	24 (0-147)	11 (0-117)	
Average, 1961-67	74.1	12.8	62.2	9.5	24.2	4.2	61.5	49.0	

1 "–" means no measurements were taken.

2 Median number of cones counted per tree. The number is the middle observation when cone counts are arranged in order of magnitude.

3 Average number and range (figures in parentheses) of cones counted per tree.

important unknown factor, however, is the quality of the seed in the succeeding crop which could be very low due to a buildup of cone insects.

Individual noble firs have produced very large numbers of cones in a given year. The present record holder is a 53-inch-d.b.h. tree at Marys Peak which produced an estimated 1,440 cones in 1965 (count x 1.5). On a basis of 500 seeds per cone,[3] we can assume about 720,000 seeds (nearly 50 pounds) were produced in a single year by this one tree! Other noteworthy trees are two at Tunnel Creek, which produced estimated totals of 1,275 and 1,080 cones, respectively, in 1962, and a 58-inch specimen at Wildcat Mountain, which produced 1,176 cones in 1965.

Pacific silver fir.--Cone production by Pacific silver fir has been nearly universally poor during the last 6 years (table 4). Two stands (Iron Mountain and Timberline Road) produced two heavy or very heavy cone crops and experienced three failures during 6 years of observation. They were the exception, however, and in most stands a single medium crop was the best recorded. These observations do not agree with the suggestion that Pacific silver fir produces good crops at 2- to 3-year intervals and light crops in intervening years (U.S. Forest Service 1948).

There has been relatively little variation between locales (table 4). All stands produced crops in 1962, although crop size varied tremendously. All locales failed completely in 1963 (except for Hunger Mountain), 1964, and 1966. Cones were recorded on all study plots in 1965, even though the crop was rated as a failure (median cone count of 0) at three of the 12 locations.

The record count for a single Pacific silver fir was 254 cones on a 22-inch specimen at Iron Mountain in 1965. With a factor of 1.7 to convert to total cones and 400 seeds per cone,[4] we can assume a production of about 173,000 seeds (15 pounds).

Mountain hemlock.--During the last 6 years, mountain hemlock has not proved so prolific a seeder as generally believed (Fowells 1965) (table 5). All plots did have at least one good year in 1962, however, with crops rated from medium at Steamboat Mountain (median count 195 – nearly a heavy rating) to very heavy in the majority of stands. Two plots (Stampede and Santiam Passes) failed to produce even a medium crop during the following 4 years, although the remainder have each produced one other crop rated as medium or better.

Some years there was little variation between localities in cone crop rating, but in others it was considerable. From 1962 to 1964 and in 1967, there was very little variation – all stands did well in 1962 and all failed the other three years. In 1965, although all plots had cones, crops were rated as medium to very heavy at four locations and very light on the remainder. Crops were failures at four localities in 1966 and light to medium at three.

Individual mountain hemlock trees produced massive quantities of cones, "... cones so numerous as to weigh down the branchlets and almost cover them" (Fowells 1965). The largest number of cones counted was 1,700 on a 20-inch tree

[3] Unpublished data, on file at Forestry Sciences Laboratory, Pacific Northwest Forest and Range Experiment Station, Corvallis, Oregon, indicate 500 seeds per cone is a conservative estimate for noble fir.

[4] Unpublished data on file at the Forestry Sciences Laboratory, Pacific Northwest Forest and Range Experiment Station, Corvallis, Oregon, indicate 400 seeds per cone is a conservative estimate for Pacific silver fir.

Table 4.--Pacific silver fir cone counts by location and year[1]

Year	Glacier Creek No. 1	Glacier Creek No. 2	Tunnel Creek	Stampede Pass	Mosquito Lakes	Spirit Lake	Bare Mountain	Timber-line Road	Santiam Pass	Iron Mountain	Hunger Mountain	Bon Jon Pass	Average
	Number[2]												
1961	17	–	–	–	–	–	–	–	–	–	–	–	17.0
1962	10	–	–	3	14	–	17	43	12	65	9	14	20.7
1963	0	0	0	0	0	0	0	0	0	0	10	0	.9
1964	0	0	0	0	0	0	0	0	0	0	0	0	0
1965	2	18	18	0	0	92	2	63	1	115	40	0	29.2
1966	0	0	0	0	0	0	0	0	0	0	0	0	0
1967	0	0	0	0	0	0	0	2	0	1	0	0	.6
Average, 1961-67	4.1	3.6	3.6	.5	2.3	18.4	3.2	18.0	2.2	30.2	9.8	2.3	
	Number and range[3]												
1961	15 (1-36)	–	–	–	–	–	–	–	–	–	–	–	15.0
1962	10 (1-25)	–	–	10 (0-52)	15 (1-34)	–	20 (0-59)	52 (11-106)	15 (2-53)	67 (10-182)	27 (0-226)	17 (0-64)	25.9
1963	0 (0-3)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	17 (0-42)	0 (0-3)	1.4
1964	0 (0-2)	0 (0-2)	0 (0-4)	0 (0-4)	2 (0-22)	0 (0-2)	1 (0-11)	2 (0-17)	0 (0-0)	3 (0-35)	0 (0-2)	0 (0-0)	.7
1965	4 (0-29)	31 (0-126)	24 (2-60)	2 (0-17)	3 (0-39)	89 (0-191)	6 (0-52)	58 (12-117)	4 (0-32)	132 (35-254)	49 (1-104)	7 (0-76)	34.1
1966	0 (0-4)	0 (0-3)	0 (0-1)	1 (0-6)	1 (0-4)	0 (0-0)	0 (0-2)	0 (0-0)	0 (0-2)	0 (0-0)	0 (0-3)	0 (0-7)	.2
1967	0 (0-0)	0 (0-0)	0 (0-5)	0 (0-1)	0 (0-3)	0 (0-0)	0 (0-3)	4 (0-24)	0 (0-4)	5 (0-28)	0 (0-0)	0 (0-0)	.8
Average, 1961-67	4.1	6.2	4.8	2.2	3.5	17.8	4.5	19.3	3.2	34.5	15.5	4.0	

1 "–" means no measurements were taken.

2 Median number of cones counted per tree. The number is the middle observation when cone counts are arranged in order of magnitude.

3 Average number and range (figures in parentheses) of cones counted per tree.

Table 5.--Mountain hemlock cone counts by location and year

Year	Heather Meadows	Stampede Pass	Steamboat Mountain	Deadman's Curve	Santiam Pass	Carpenter Mountain	Windigo Pass	Average
	Number[1]							
1962	350	260	195	265	600	380	300	335.7
1963	0	0	0	0	0	0	0	0
1964	4	0	0	0	0	3	0	1.0
1965	37	30	198	250	28	420	150	159.0
1966	120	95	96	7	8	1	0	46.7
1967	0	0	0	0	0	0	0	0
Average, 1962-67	85.2	64.2	81.5	87.0	106.0	134.0	75.0	
	Number and range[2]							
1962	400 (100-1,000)	293 (20-1,190)	224 (45-700)	402 (10-1,140)	740 (200-1,700)	471 (90-1,500)	263 (0-600)	399.0
1963	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0
1964	10 (0-40)	3 (0-16)	0 (0-4)	1 (0-10)	0 (0-0)	6 (0-34)	67 (0-300)	12.4
1965	72 (0-460)	40 (0-130)	311 (55-780)	320 (30-1,440)	76 (5-465)	401 (80-1,080)	174 (40-580)	199.1
1966	168 (14-600)	121 (8-350)	96 (0-225)	13 (0-91)	17 (0-66)	2 (0-8)	1 (0-10)	59.7
1967	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-5)	0
Average, 1962-67	110.0	76.2	105.2	122.7	138.8	146.7	84.2	

[1] Median number of cones counted per tree. The number is the middle observation when cone counts are arranged in order of magnitude.

[2] Average number and range (figures in parentheses) of cones counted per tree.

located at Santiam Pass in 1962. This represents production of about 350,000 seeds (3 pounds) if we assume a conversion factor of 2.0 and 100 seeds per cone. Over 1,000 cones were counted on many other trees during the 5-year study period.

Western white pine.--Western white pine has been a consistent cone producer (table 6). Complete failures have been rare except on two plots located in the Wenatchee Province (Franklin 1965) – Lake Wenatchee and Big Meadows Creek. Five other stands, for which there is a 5- or 6-year record available, have produced at least one heavy crop; three have always produced at least a very light crop.

A general pattern of cone periodicity ties most of the plots together – good crops in 1962, 1964 and 1967, poor ones in 1963 and 1966, and a fair crop in 1965. There are still exceptions, however, particularly at the Wenatchee plots already noted and in the extreme southern Oregon Cascade Range and Siskiyou Mountains. Only one plot record is available for the latter area (Bessie Rock), but supplemental observations showed heavy western white pine crops were general in the southern Cascade Range and eastern Siskiyou Mountains in 1963 and 1966.

The maximum count for a single western white pine is 400 cones – counted in 1964 on a 36-inch specimen at Big Meadows Creek. Using 1.5 for a count conversion factor and 120 seeds per cone (Haig et al. 1941), we can assume about 72,000 or 27 pounds of seed. This record white pine cone count is identical with that reported by Haig et al. (1941) from northern Idaho.

Other species.--Limited records of cone production by subalpine fir, grand fir, Shasta red fir, and Engelmann spruce have been obtained (table 7). All four subalpine fir plots produced at least one medium crop during the last 4 years, and trees at Big Meadows Creek have produced both heavy and very heavy crops. Thus far there appears to be little yearly correlation between plots except that all three studied in 1963 had cone failures and all four failed or nearly so in 1967. A maximum count of 510 cones was produced by a 25-inch-d.b.h. tree growing at Big Meadows Creek in 1963.

For the last 5 years, grand fir has been a fairly prolific cone producer in the three areas studied. Two plots had two very heavy crops and three failures or very light crops. The third, Lost Prairie, had medium and heavy crops in 2 of 5 years of observation. Cone production on the Washington plots has shown an identical pattern with good years in 1964 and 1966 and poor ones in 1963, 1965, and 1967. Lost Prairie differed with a medium crop in 1965 and light crops in 1966 and 1967. A maximum count of 580 cones was made on a 31-inch-d.b.h. tree at Big Meadows Creek in 1964.

Engelmann spruce also seems to produce large cone crops at frequent intervals. At Big Meadows Creek, medium to very heavy cone crops have been produced in 3 out of 5 years; heavy and very heavy crops have been produced at Lost Creek in 2 of 5 years.

Yearly periodicity of the two plots shows almost no correlation; indeed, the reverse is suggested – spruce at one locale produce a good crop at the same time cone production fails at the other.

Variation in Cone Production Within Plots

Individual dominant specimens of the same species at the same locale varied significantly in cone-producing capacity.

Table 6.--Western white pine cone counts by location and year[1]

Year	Lake Wenatchee	Big Meadows Creek	Smithbrook	Peterson Prairie	Bear Paw	Santiam Pass	Lost Prairie	Windigo Pass	Bessie Rock	Average
					Number[2]					
1962	0	—	—	50	34	41	—	58	—	36.6
1963	0	0	—	3	2	12	6	0	—	3.3
1964	—	126	8	110	77	54	8	38	—	60.1
1965	—	0	10	10	13	11	35	34	—	16.1
1966	—	0	9	16	2	2	0	2	59	11.2
1967	—	0	0	90	13	54	21	5	9	24.0
Average, 1962-67	0.0	25.2	6.8	46.5	23.5	29.0	14.0	22.8	34.0	
					Number and range[3]					
1962	3 (0-3)	—	—	55 (19-127)	42 (6-127)	50 (5-105)	—	74 (0-225)	—	44.8
1963	1 (0-9)	0 (0-2)	—	14 (0-62)	6 (0-24)	16 (0-44)	18 (0-60)	4 (0-44)	—	8.4
1964	—	142 (16-400)	37 (0-165)	122 (55-259)	76 (0-206)	64 (3-267)	39 (2-148)	53 (0-144)	—	76.1
1965	—	5 (0-61)	25 (0-189)	19 (0-76)	30 (0-198)	12 (0-40)	36 (3-78)	49 (0-157)	—	25.1
1966	—	1 (0-10)	26 (0-105)	19 (0-46)	6 (0-26)	5 (0-16)	4 (0-18)	4 (0-25)	70 (0-228)	16.9
1967	—	2 (0-29)	7 (0-41)	85 (6-210)	22 (0-111)	75 (0-165)	23 (0-100)	8 (0-42)	11 (0-30)	29.1
Average, 1962-67	2.0	30.0	23.8	52.3	30.3	37.0	24.0	32.0	40.5	

1 "—" means no measurements were taken.

2 Median number of cones counted per tree. The number is the middle observation when cone counts are arranged in order of magnitude.

3 Average number and range (figures in parentheses) of cones counted per tree.

Table 7.–Subalpine fir, grand fir, Shasta red fir, and Engelmann spruce cone counts by location and year[1]

Year	Subalpine fir					Grand fir				Shasta red fir			Engelmann spruce		
	Smith-brook	Big Meadows Creek	Steamboat Mountain	Sand Mountain	Average	Big Meadows Creek	Peterson Prairie	Lost Prairie	Average	Windigo Pass	Bessie Rock	Average	Big Meadows Creek	Lost Creek	Average
	Number[2]														
1962	–	–	53	15	34.0	–	–	–	–	6	–	6.0	–	–	–
1963	–	0	0	0	0.0	0	1	0	0.3	0	–	0.0	0	285	142.5
1964	50	140	3	0	48.2	340	150	50	180.0	8	–	8.0	480	0	240.0
1965	10	0	28	44	20.5	0	2	36	12.7	25	–	25.0	115	570	342.5
1966	0	63	3	0	17.2	265	300	16	193.7	0	0	0.0	120	25	72.5
1967	0	0	1	0	0.2	0	0	11	3.7	0	6	3.0	0	160	80.0
Average, 1962-67	15.0	40.6	14.7	9.8		121.0	91.2	22.6		6.5	3.0		143.0	208.0	
	Number and range[3]														
1962	–	–	61 (1-150)	31 (0-104)	46.0	–	–	–	–	12 (0-59)	–	12.0	–	–	–
1963	–	1 (0-18)	0 (0-0)	0 (0-0)	0.3	3 (0-28)	4 (0-20)	3 (0-15)	3.7	1 (0-5)	–	1.0	23 (0-200)	462 (0-2,570)	242.5
1964	47 (0-152)	151 (0-510)	10 (0-50)	8 (0-71)	54.0	311 (65-580)	186 (40-448)	53 (18-95)	183.3	10 (0-42)	–	10.0	542 (25-1,360)	2 (0-20)	272.0
1965	13 (0-48)	0 (0-7)	40 (0-136)	50 (0-160)	25.8	0 (0-0)	2 (0-11)	38 (2-110)	10.0	24 (0-76)	–	24.0	215 (20-3,100)	809 (20-2,580)	512.0
1966	0 (0-1)	95 (10-280)	13 (0-72)	0 (0-0)	27.0	274 (74-560)	291 (79-600)	24 (0-86)	196.3	0 (0-0)	0 (0-0)	0.0	374 (10-3,200)	75 (0-400)	224.5
1967	3 (0-20)	5 (0-54)	7 (0-89)	0 (0-0)	3.8	0 (0-0)	0 (0-0)	15 (0-59)	5.0	3 (0-15)	13 (0-64)	8.0	4 (0-40)	271 (0-1,290)	137.5
Average, 1962-67	15.8	50.4	21.8	14.8		117.6	96.6	26.6		8.3	6.5		231.6	323.8	

1 "–" means no measurements were taken.
2 Median number of cones counted per tree. The number is the middle observation when cone counts are arranged in order of magnitude.
3 Average number and range (figures in parentheses) of cones counted per tree.

Statistical analyses were conducted on data from 33 of the cone plots, including at least one of each species, which had 2 or more years of light or better cone crops.[5] Variability between trees was significant or highly significant on 20 of these plots and approached significance on several of the others.

Regression analyses of cone production on tree diameter were then conducted on the 20 plots which showed significant variability between trees. On six, tree diameter and cone production were significantly related; i.e., diameter accounted for part of the variation in cone production between individual trees. However, this generally occurred on plots with a wide variation in diameter of the study trees; e.g., tree diameter on the Peterson Prairie white pine plot (one on which diameter and cone production are related) ranges from 14 to 45 inches, although all study trees are dominants. The normal range of tree diameters on study plots is 10 to 15 inches; under this condition, diameter was generally not significantly correlated with cone production.

In general and for the species under study, some trees apparently have an inherent capacity to produce more cones than other trees of the same species, and this is not accounted for by diameter differences in most even-aged stands. This finding is not surprising since geneticists and horticulturists have recognized inherent differences in flowering ability for many years. But it does have important implications in the selection of seed trees.

Do all trees of a given species at a locale show the same pattern of periodicity or rhythm of cone production? It was not possible to test this tree-year interaction statistically. Inspection of the data suggests that individual trees may occasionally be out of phase with the bulk of the population. This seems to be particularly common in years with intermediate levels of cone production.

SILVICULTURAL IMPLICATIONS

Frequency of Cone Crops

Six years of data are too few to allow predictions regarding frequency with which individual species will produce large cone crops. There are indications that western white pine and noble fir, in most localities, are fairly dependable cone producers. Engelmann spruce and grand fir have also produced large cone crops at frequent intervals, although observations have been made in only a few stands and for only 5 years. Mountain hemlock has not proved so prolific as previously believed.

Pacific silver fir has thus far been a disappointing cone producer at most locations. If this proves to be the general situation, silvicultural systems for natural regeneration of Pacific silver fir will have to provide a seed source over a considerable period of time, as in shelterwood or selective cutting. The necessity for these systems is emphasized when the short dissemination distance for silver fir seed is

[5] Statistical theory required rejection of years of record in which most trees had 0 cones.

considered along with its apparent low cone-bearing capacity. Hetherington (1965) showed most silver fir seed on Vancouver Island falls within 50 to 100 feet from the edge of the cutting area.

Available data do indicate the forester can expect some seed from at least one upper-slope species almost every year (table 8). This is important since most upper-slope stands are composed of mixtures of several species. The forester is, therefore, not dependent on cone production by a single species, unless he specifically desires regeneration of that species.

There are some years in which all species in a locale fail to produce cones. This happened in 1963 when almost no cones were produced by any species studied in Washington and northern Oregon, and again in 1966 in Oregon and in 1967 in northern Washington (table 8). More commonly, however, when some species are experiencing cone failures, others are producing crops. See, for example, the Mount Adams area in 1962 and 1964 through 1967 and the Santiam Pass and Willamette Province areas from 1962 through 1965 and in 1967 (table 8). Other upper-slope species, particularly Douglas-fir and western hemlock, will also contribute seed, and their pattern of cone production is not necessarily in phase with the species included in this study. For example, in 1966, upper-slope Douglas-fir and western hemlock were observed to produce better-than-average crops of cones in many localities in Oregon while associated true firs and mountain hemlock were experiencing failures.

The observation that species growing in mixed stands are often out of phase with one another in level of cone production is confirmed by other studies. Haig et al. (1941) concluded that "little consistency between species is evident" when he compared cone crops of western white pine, western larch, Douglas-fir, grand fir, western redcedar, and western hemlock in northern Idaho. Even in the poorest year he recorded, two of the six species had fair crops. Similarly, ponderosa pine, sugar pine, and white fir cone crops failed simultaneously in only 4 out of 16 years of record in a portion of the Sierra Nevada (Fowells and Schubert 1956).

Selection of Leave Trees

In selecting leave trees on partial cuttings, an important objective is to leave the most prolific seed producers. Highly significant differences in cone bearing between dominant full-crowned specimens in a single locale were demonstrated for all species included in this study. It is not the occurrence but the magnitude of the differences which are surprising.

The importance of care in selection of leave trees for maximum seed production, even when all are dominants, is illustrated in tables 9 and 10. For selected plots, trees were grouped by three criteria: (1) those most productive of cones over the period of record; (2) those largest in diameter; and (3) those of average cone productivity for the plot, presumably approximating what might be obtained from a random selection of dominant trees. Ten trees (table 9) simulates the number of dominants which might be left on an acre after heavy shelterwood cutting. Two trees per acre (table 10) is typical of a seed tree cutting.

If a forester selected, through some happy circumstance, the 10 trees most productive of cones, he might expect about twice as much seed over 4 or 5 years as would be produced by a random selection of dominants (table 9). On the study plots,

Table 8.--Yearly comparison of cone crop ratings between species as observed in the same general locality[1]

Locality and species[2]	1962	1963	1964	1965	1966	1967
Mount Baker:						
Pacific silver fir (Glacier Creek)	3	0	0	3	0	0
Mountain hemlock (Heather Meadows)	5	0	0	1	3	0
Stevens Pass:						
Noble fir (Tunnel Creek)	5	0	2	1	4	0
Pacific silver fir (Tunnel Creek)	—	0	0	3	0	0
Western white pine (Smithbrook)	—	—	2	3	2	0
Subalpine fir (Smithbrook)	—	—	4	2	0	0
Big Meadows Creek:						
Western white pine	0	0	5	0	0	0
Subalpine fir	—	0	5	2	0	0
Grand fir	—	0	5	0	5	0
Engelmann spruce	—	0	5	3	3	0
Stampede Pass:						
Noble fir	3	0	1	0	0	2
Pacific silver fir	1	0	0	0	0	0
Mountain hemlock	4	0	0	1	2	0
Mount Adams:						
Noble fir (Sleeping Beauty)	3	0	0	0	3	3
Pacific silver fir (Mosquito Lakes)	3	0	0	0	0	0
Mountain hemlock (Steamboat Mountain)	3	0	0	3	2	0
Western white pine (Peterson Prairie)	5	1	5	3	3	5
Grand fir (Peterson Prairie)	—	1	5	1	5	0
Subalpine fir (Steamboat Mountain)	4	0	1	3	1	1
Mount Hood:						
Noble fir (North Wilson)	1	0	0	0	0	3
Pacific silver fir (Timberline Road)	4	0	0	5	0	1
Mountain hemlock (Deadman's Curve)	4	0	0	4	0	0
Western white pine (Bear Paw)	4	1	5	3	1	3
Santiam Pass:						
Pacific silver fir	3	0	0	1	0	0
Mountain hemlock	5	0	0	1	0	0
Western white pine	4	3	5	3	1	5
Subalpine fir (Sand Mountain)	2	0	0	3	0	0
Engelmann spruce (Lost Lake Creek)	—	4	0	5	1	3
Willamette Province:						
Pacific silver fir (Wildcat Mountain)	5	0	0	5	0	1
Noble fir (Iron Mountain)	5	3	1	5	0	3
Mountain hemlock (Carpenter Mountain)	5	0	0	5	0	0
Western white pine (Lost Prairie)	—	2	2	4	0	4
Grand fir (Lost Prairie)	—	0	4	3	2	2
Windigo Pass:						
Shasta red fir	2	0	2	4	0	0
Mountain hemlock	5	0	0	3	0	0
Western white pine	5	0	4	4	1	2

[1] Crop ratings are 0 = failure, 1 = very light, 2 = light, 3 = medium, 4 = heavy, and 5 = very heavy.

[2] Where the plot name is different from the locality designation, it is given in parentheses.

Table 9.--Estimated total production of viable seed[1] *on some plots by groups of 10 study trees selected by three different criteria*

Species and plot[2]	Best cone producers	Largest d.b.h. trees	Average cone producers	Largest d.b.h. trees	Average cone producers
	Thousands of seed			*Percent of best producers*	
Noble fir, Willame Creek	994	817	575	82	58
Noble fir, Wildcat Mountain	879	813	472	92	54
Pacific silver fir, Timberline Road	201	168	133	84	66
Pacific silver fir, Iron Mountain	430	401	268	93	62
Mountain hemlock, Deadman's Curve	1,090	700	465	64	43
Western white pine, Windigo Pass	164	112	73	68	44
Subalpine fir, Steamboat Mountain	178	125	113	70	64
Grand fir, Big Meadows Creek	743	575	584	77	79

[1] Calculation of viable seed based on cone counts x conversion factor (to total cone production) x number of seeds per cone x percent viable seed according to the "Woody-Plant Seed Manual" (U.S. Forest Service 1948). Factors used were:

Species	*Conversion factor*	*Seeds per cone*	*Percent viable seed*
Noble fir	1.5	500	24
Pacific silver fir	1.7	400	22
Subalpine fir	1.7	150	38
Grand fir	1.7	200	28
Western white pine	1.5	120	48
Mountain hemlock	2.0	100	47

[2] Grand fir and western white pine data include a 4-year period; the remainder, a 5-year span.

Table 10.--Estimated total production of viable seed[1] on some plots by groups of two study trees selected by three different criteria

Species and plot[2]	Best cone producers	Largest d.b.h. trees	Average cone producers	Largest d.b.h. trees	Average cone producers
	Thousands of seed			*Percent of best producers*	
Noble fir, Willame Creek	269	156	115	58	43
Noble fir, Wildcat Mountain	329	268	94	81	29
Pacific silver fir, Timberline Road	51	34	27	67	52
Pacific silver fir, Iron Mountain	115	96	54	84	47
Mountain hemlock, Deadman's Curve	428	134	93	31	22
Western white pine, Windigo Pass	46	13	14	28	32
Subalpine fir, Steamboat Mountain	54	18	23	14	42
Grand fir, Big Meadows Creek	206	102	117	50	57

[1] Calculation of viable seed based on cone counts x conversion factor (to total cone production) x number of seeds per cone x percent viable seed according to the "Woody-Plant Seed Manual" (U.S. Forest Service 1948). Factors used were:

Species	*Conversion factor*	*Seeds per cone*	*Percent viable seed*
Noble fir	1.5	500	24
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Grand fir	1.7	200	28
Western white pine	1.5	120	48
Mountain hemlock	2.0	100	47

[2] Grand fir and western white pine data include a 4-year period; the remainder, a 5-year span.

selection of the 10 largest trees would have improved seed yields significantly over a random selection of trees (except in the case of grand fir at Big Meadows Creek). Cone production by the 10 largest noble and Pacific silver firs approached 80 to 90 percent of the yield of the most productive group of 10 trees.

With only two trees per acre left as a reserve, selection of the best seed producers was critical (table 10). Seed yields of the average producers were only 22 to 57 percent of the two most productive trees. Because the two biggest trees were not necessarily the most prolific, their selection as leave trees would have resulted in seed yields only slightly better than, or even inferior to, those obtained from a random selection of trees – the average producers.

How can the forester identify the best cone producers when selecting leave trees in partial cuttings? The following guidelines may be helpful:

1. Select only dominant full-crowned trees. Specimens of other crown classes may provide shelter but will produce little or no seed.

2. If trees are being marked during a good seed year, select those with the greatest abundance of cones. With a few exceptions, trees that produced large numbers of cones during a good seed year were consistently top-ranking producers over the long run.

3. If marking is going on during a poor seed year, use other indicators of cone productivity – spikes left from previous cone crops in crowns of true firs, old cones left in crowns of mountain hemlock, and old cones around the bases of white pines.

4. When marking for a shelterwood cutting, with 10 or more dominants as leave trees, a selection of the largest specimens will usually include a high proportion of the best cone producers. However, when only two leave trees per acre are required, use of diameter as a criterion of cone production may be a risky one and a poor substitute for carefully searching out the most prolific trees.

With care in selection of leave trees, the forester can greatly increase seedfall on his partial cuttings. This could greatly improve the chances for rapid natural regeneration.

CONCLUDING NOTE

Plans are to continue this study for many more years to strengthen information on cone crop periodicity of upper-slope species. Other aspects of seed supply under investigation are yearly variation in viable seed and damaging agents, total seed production of selected stands, and timing, distance, and direction of seed dispersal on cutover areas. Results of these studies will be related to fluctuations in cone crop levels found in this study.

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Cone production by mature noble, Pacific silver, subalpine, grand and Shasta red firs, western white pine, mountain hemlock, and Engelmann spruce trees has been observed annually since 1961. Generally, cones are produced by one or more species every year. Significant intraspecific differences in cone production between dominants make selection of the most prolific as leave trees important in partial cuttings.

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